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IMPACT OF A ONCE THROUGH COOLING SYSTEM ON THE YELLOW PERCH STOCK IN THE WESTERN BASIN OF LAKE ERIE

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An analytical model was also applied. Parameters of the analytical model were estimated using power plant data, biological data available in the literature, and commercial catch data. The model was used to estimate the age structure and biomass of the perch stock and to estimate the impact of the power plant on abundance of the impingeable stock and biomass of the exploited stock. The level of impact was examined under a range of mortality conditions. The two models are much different in terms of mathematical structure and in terms of the data applied for estimation of parameters, but give similar estimates of impact of about a 1% to 3% reduction in the size of the exploited stock.

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SECTION 1

INTRODUCTION

The Monroe Power Plant is a 4 unit 3150 megawatt coal fired plant located on the western shore of Lake Erie south of the Raisin River (Fig. 1). The plant uses once through cooling and has a pumping capacity of 0.29×10^{10} m^3/yr. The water is pumped from the Raisin River and Lake Erie. A full discussion of plant operation and entrainment and impingement at the plant are provided by Anon. (1976), Cole (1978), and Patterson (1979).

The yellow perch (Perca flavesences) is one of the most frequently impinged and entrained fish at the power plant and the yellow perch is a highly valued sport and commercial fish in Lake Erie. Considerable information on this species is available, and much of the biological information for the species has been summarized in the synopsis by Thorpe (1977).

For assessment of the impact of entrainment and impingement of the Monroe Power Plant on the yellow perch stock of western Lake Erie two conventional fishery assessment models are applied. First the surplus production model is applied. Commercial catch and effort data are applied to estimate the model parameters. The fitted model is applied to estimate stock size and the number of eggs and larvae

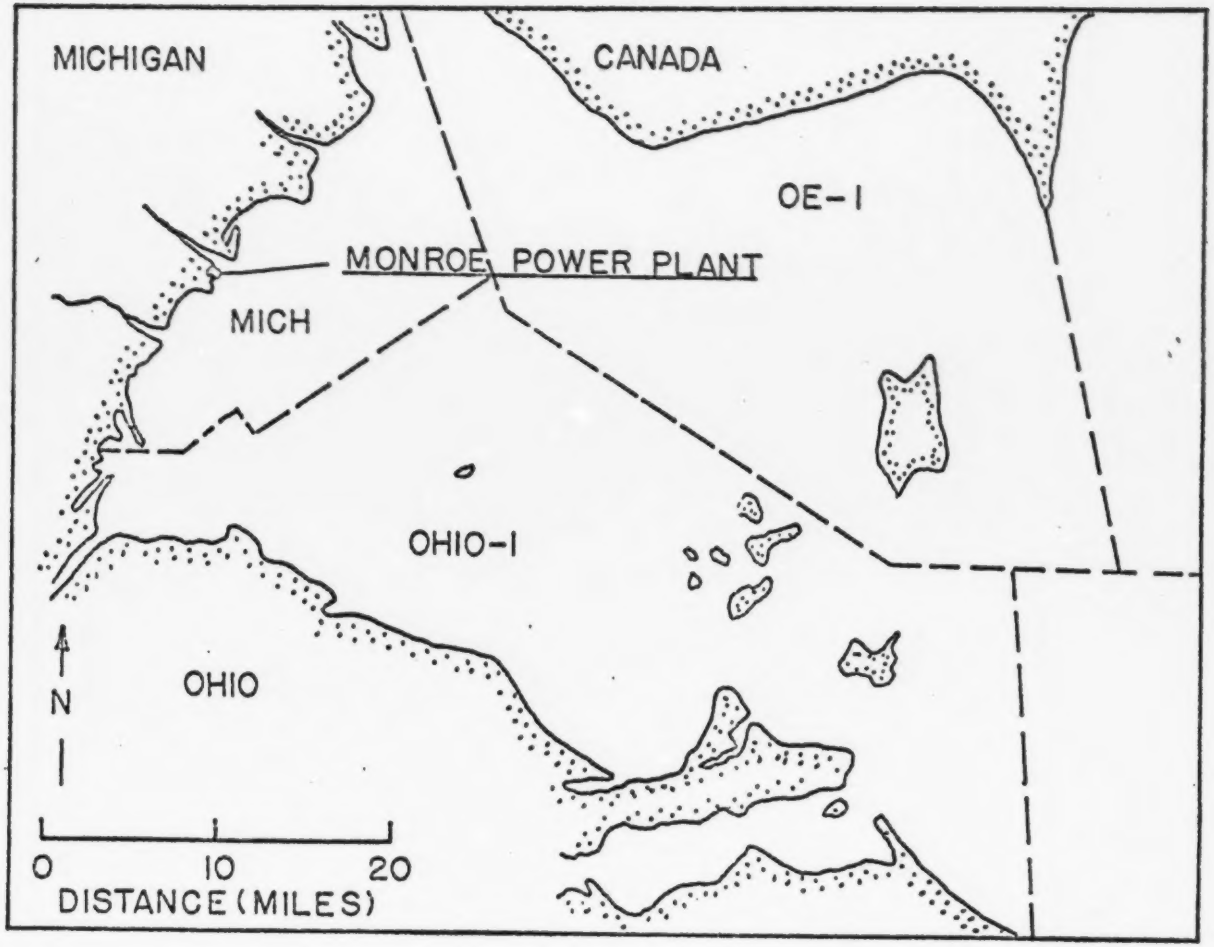

Figure 1. Western Lake Erie showing location of the Monroe Power Plant and the fishery statistical districts Mich, OE-1, and Ohio-1.

SECTION 2

HISTORY OF THE LAKE ERIE FISHERY

Lake Erie is the most productive of the Great Lakes in terms of fish harvest. In all but four years since 1914 Lake Erie has led the other Great Lakes in commercial landings. Lake Michigan's production has exceeded that of Lake Erie recently because of the increased alewife catch but Lake Erie remains foremost in value of harvest (Leach and Nepszy, 1976). Lake Erie continues to produce about 50 million pounds of fish per year, about 50 percent of the total production of the Great Lakes (Baldwin and Saalfeld, 1962), however, the species composition has changed markedly over the years.

The nineteenth century Lake Erie fishery was characterized by an abundance of the so called high-value species; ciscoe, lake whitefish, and lake trout. By the end of the century, fishing pressure began to have severe effects on some of the slow-growing, late maturing, long-lived species such as the lake trout (Applegate and VanMeter, 1970). In order of importance, the major species caught commercially in 1899 were ciscoe, blue pike (subspecies of walleye), carp, yellow perch, sauger, lake whitefish, and walleye (Beeton, 1970).

produced. The model also is applied to determine the proportion of the standing stock impinged and the proportion of larvae entrained, and to determine the impact of entrainment and impingement on the standing stock and the maximum sustainable yield. The impingement and entrainment estimates reported by Cole (1978) and Patterson (1979) are used in applying the surplus production model. The impact on the biomass of the stock and maximum sustainable yield of increased water withdrawls are simulated.

An analytical or dynamic pool model also is applied. Biological data from the literature and power plant data are applied to estimate parameters. The estimates of entrainment and impingement made by Detroit Edison (Anon. (1976) are applied for this assessment. The impact on total population size and the fishable biomass is assessed under a range of natural and fishing mortality conditions.

In the early part of the twentieth century, there was a steady decline in the total Lake Erie fishing. This has been largely attributed to the decline of the ciscoe population in the mid-1920s. By that time, the lake sturgeon and northern pike already had been reduced to insignificant numbers mainly because of exploitation, and by the mid-1930s the lake trout was commercially extinct as well (Applegate and VanMeter, 1970). The decline of these species was somewhat compensated for, however, by the increased harvesting of walleye and yellow perch. By 1940, the commercial fishery was dominated by blue pike, lake whitefish, yellow perch, walleye, freshwater drum, carp, and white suckers (Beeton, 1970).

Since 1940 the fish populations have changed dramatically. Lake whitefish landings, which had declined abruptly in the Western basin in the 1920s, declined lakewide in the mid 1950s (Applegate and VanMeter, 1970). Sauger populations, which had declined steadily since 1915, fell to the level of commercial extinction between 1946 and 1958 (Applegate and VanMeter, 1970). Blue pike production during the first half of the century displayed no long-term trends despite extreme annual fluctuations. However, after an unprecedented

drop in the commercial catch in 1958, the fishery declined to negligible levels in 1959 (Applegate and VanMeter, 1970). Blue pike are now considered rare or extinct. Ciscoes continue to decline despite a relatively successful 1944 year class and they were commercially insignificant by 1960.

The commercial fishery then turned to the less valuable species that were becoming more abundant, such as the yellow perch and rainbow smelt. Yellow perch harvests increased in the 1950s due to an intensified fishery and several successful year classes (Hartman, 1972). Rainbow smelt, introduced into Lake Erie in the 1930s, have become increasingly important to the commercial fishery since 1952. Thus, in 1968 the fish species in order of importance consisted of yellow perch, rainbow smelt, freshwater drum, carp, white bass, channel catfish, and walleye (Beeton, 1970). Recently, there have been bans on commercial harvest of walleye and white bass due to high levels of mercury (Leach and Nepszy, 1976).

Possible explanations for the changes in the fishery are numerous, and center around five points: (1) exploitation by the commercial fishery, (2) cultural eutrophication, (3) the invasion or introduction

of exotic species, (4) tributary and shoreline restructuring, and (5) turbidity and siltation. Fishing pressure has provided a significant yet difficult-to-quantify stress. Oxygen depletion and the associated changes in the benthos, in conjunction with the toxicities of pesticides and other contaminants, may have contributed to the decline of species such as the blue pike and sauger in the Western basin. Invasion by the sea lamprey has had little affect on Lake Erie fish populations because the tributaries fail to support a spawning sea lamprey population (Hartman, 1972). The alewives have also failed to become established in as great abundance as in other Great Lakes. However, other exotic species such as the rainbow smelt, carp, and goldfish have become well established, and undoubtedly provide a competitive force against the various life stages of many indigenous species. Tributary and shoreline restructuring, as well as turbidity and siltation, have reduced the areas available for successful spawning of many species.

SECTION 3

THE YELLOW PERCH OF LAKE ERIE

The yellow perch, *Perca flavescens* (Mitchell) is one of the most important and widely distributed food fish of the northeastern United States and southeastern Canada. It inhabits the Great Lakes, inland lakes, and large streams but is never plentiful in Lake Superior (el-Zarka, 1959). Because of this wide distribution and its frequent great abundance, the yellow perch has become important to both commercial fishermen and anglers in many locations. It is well known that in many areas, the anglers annually remove more yellow perch than do the commercial fishermen. Despite the wide range of this species, the commercial production of yellow perch is mainly concentrated in Lake Erie (especially the Western basin), Green Bay in Lake Michigan, and Saginaw Bay in Lake Huron.

The earliest records of the production of yellow perch in Lake Erie are for the year 1885 (Figure 2). The species was taken commercially before that time but it was not considered important enough to warrant separate treatment in the earlier statistical reports.

The Ohio production has always dominated the United States catch, and for years for which complete data are

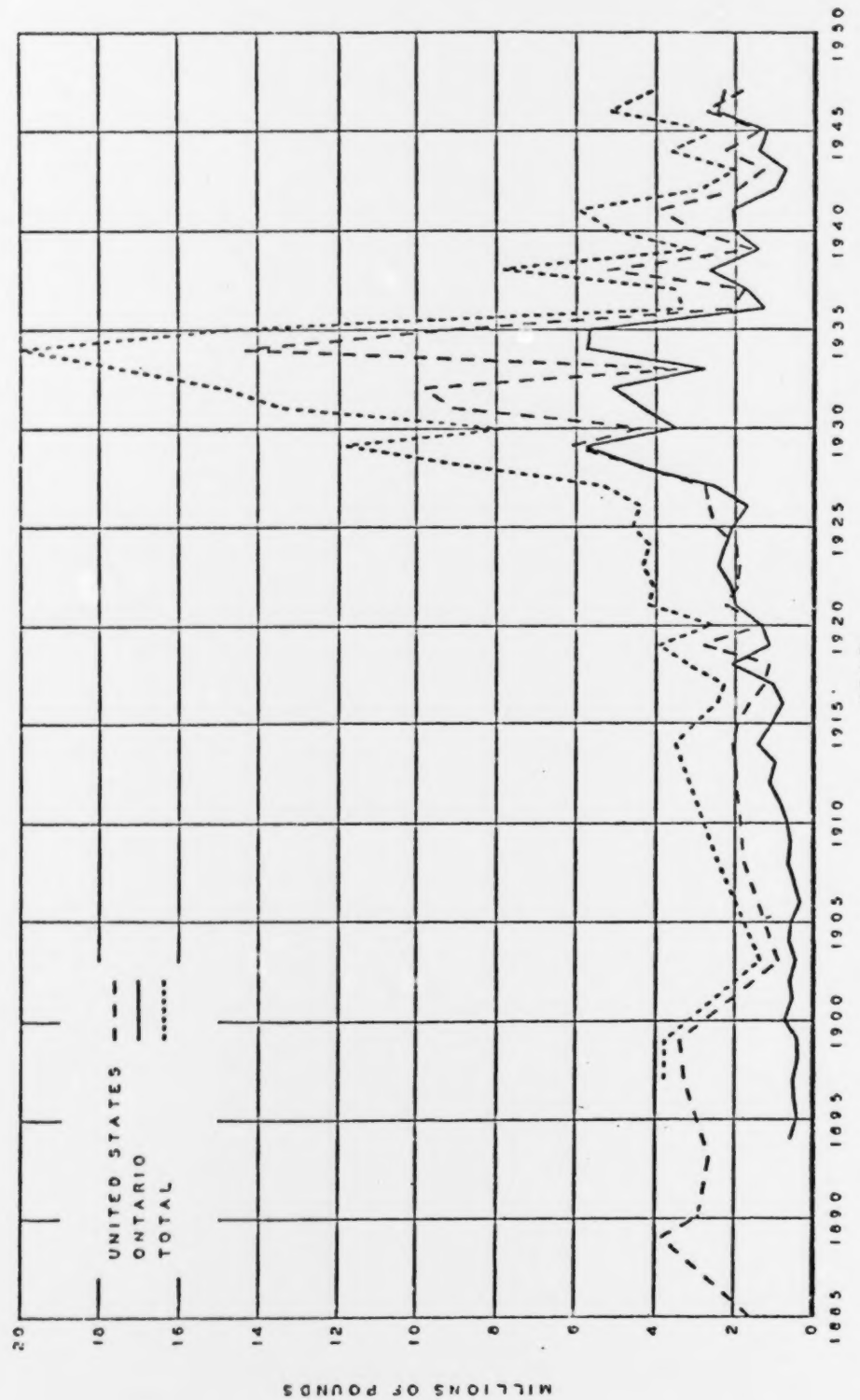

Figure 2 Annual production of yellow perch in Lake Erie, 1885-1947 (from Jobes, 1952).

available, Ohio on the average has accounted for more than half of the yield of the entire lake. Furthermore, the relative importance of the Ohio catch in the United States production has shown a distinct tendency to increase. In the early period, 1885-1899, Ohio produced 77.8 percent of the total United States yield. This percentage increased to 87.7 in the 1900-1927 period, to 92.9 in 1928-35, and to 93.1 in recent years (Jobes, 1952).

The abundance of yellow perch during the early period of the United States fishery (1885-1899) must have been relatively high since good production was maintained inspite of low fishing intensity and inefficient methods. On the other hand, the reduced yields of the 1900-1927 period, one of expanding fishing intensity and increased efficiency, indicate a sharp reduction in the general level of abundance (Jobes, 1952). The greatly increased production in 1928-1935 must be considered the result, at least in part, of the increase in intensity of the fishery for perch that followed the collapse of the ciscoe fishery (Jobes, 1952).

The statistics strongly suggest that the abundance of yellow perch was reduced greatly during the years 1936-1947. Hartman (1972) reported that since the late 1950s strong year classes have only occurred in 1962, 1965, and 1970. There is also an indication that the fishery is becoming dependent upon smaller and younger fish. The greatest production during 1960-1973 has been from Canadian waters.

Three and four year old fish contributed significantly to the fishery in the 1960s. However, analysis of recent Canadian catches shows a dominance by two and three year old fish. This trend towards smaller and younger fish is evidence that fewer perch are surviving to maturity. The effect can be detrimental to the fishery by reducing potential egg deposition and recruitment.

Since 1970, year-classes of yellow perch have not been strong. Reduced production in 1970 reflected the depletion of the strong year-class hatched in 1965. Catches in 1972 and 1973 were dependent on the fair year-classes of 1970 and 1971, respectively (Leach and Nepszy, 1976).

The yellow perch has now become the dominant species in the commercial harvest of Lake Erie. Although total lake landings of yellow perch have increased slightly since 1971, this does not necessarily indicate increased abundance of the stocks. The population continues to exhibit signs of stress and deterioration (Leach and Nepszy, 1976). It is experiencing poor recruitment coincident with increasing exploitation of younger fish. This, coupled with decreased catch per unit effort, contribute to the great concern over the present and future status of this fishery.

SECTION 4

THE MONROE POWER PLANT

The Monroe Power Plant, operated by the Detroit Edison Company, is a coal-fired, electric generating station located on the western shore of Lake Erie just south of the confluence of the Raisin River (Figure 3). All four of the plant's generating units were completed by mid 1974 with a net total capability of 3,150 megawatts. The water demand of the once-through cooling system depends on power production and ambient water temperature, but the maximum requirement is about 85 m^3 per second, which is about 2.8 billion m^3 per year. The water is pumped in varying proportions from the Raisin River and Lake Erie. During spring runoff, the Raisin River may contribute more than 95 percent of the cooling water whereas it contributes less than 5 percent during the low flow of late summer (Cole, 1978). The biota of the lake and river sources differs, so the species composition in the water passing through the condenser system reflects changes in proportions of source-water as well as natural and seasonal fluctuations.

Water enters the cooling system through a 100 meter long intake canal located about 650 meters upstream from

the river mouth. Prior to condenser entry, the water passes through a traveling screen with 1 cm diagonal openings. Water then enters the condenser where water velocities usually exceed 2 m/sec and the temperature rises to about 10°C above ambient at full pumping and power production.

The cooling system has a 27,917 m^2 double-flow Type M single pass divided surface condenser with 18,154 tubes. Each tube has an effective length of 17.6 inches and an outside diameter of 2.54 centimeters. The heating condenser water is released into a 350 meter long concrete conduit with water veolcities at about 1 m/sec at full operation. The discharge passes into a 2,000 meter long rock-walled discharge canal. At full pumping, the upper discharge canal velocities average about 6 cm/sec and lower canal velocities average about 12 cm/sec.

At full operation, time of water passage through the cooling system averages nearly 4.5 hours. Calculated passage times through the three main parts of the cooling system were: 7 seconds through the condenser, 20 minutes through the concrete conduit, and 4 hours through the discharge canal (Cole, 1978).

After leaving the discharge canal the heated effluent forms a plume which extends up to 6 km from the

mouth of the canal. The plume position and size depend on the pumping rate, power generation rate and the direction and velocity of the wind. Heat dissipation from the plume occurs in one or two days (Cole, 1978).

In this study it has been assumed that impinged or entrained fish are killed.

SECTION 5

APPLICATION OF THE SURPLUS PRODUCTION MODEL

Model Development

In stock assessment the conventional approach is to divide the stock into a recruited portion which is vulnerable to fishing and a non-recruited portion which is younger life stages that are not vulnerable to fishing. Stock assessment models are constructed for the recruited stock. Biomass is added to the exploited stock by growth and recruitment and biomass is lost through natural mortality and fishing mortality. Surplus production is the amount of biomass that can be removed from a population without causing a change in the size of the population. Biomass removed is exactly replaced by growth and recruitment. Surplus production is small at both high and low population sizes and attains a maximum at some intermediate population size.

The mathematical form of the logistic surplus production model is (Jensen 1978)

$$\frac{dY}{dt} = q\,E\,B$$
$$\frac{dB}{dt} = kB - \frac{k}{B_\infty} B^2 - q\,E\,B \qquad (1)$$

where: Y = cumulative yield from the fishery

q = catchability coefficient

E = fishing effort

B = biomass of the exploited stock

k = population growth coefficient

B_∞ = environmental carrying capacity

The surplus production model was developed in the late 1920's and 1930's by Volterra (1928), Hjort, et al (1933), and Graham (1935), and it has been widely applied for stock assessment (Jensen 1976, 1978; Pella and Tomlinson 1969; Fox 1970; and Schaeffer 1954, 1957). The model has been verified in laboratory studies of fish subjected to exploitation (Silliman and Gutsell 1958) and the model is a commonly applied biological model for bioeconomic analyses of fisheries (Anderson 1977). The assumptions of the model have been discussed in detail in the above papers; especially by Jensen (1976) and Pella and Tomlinson (1969). The surplus production model has been applied to estimate stock size, the maximum sustainable yield, optimum fishing effort, and

catch quotas.

If the fishery and impingement operate on the same portion of the stock the surplus production model easily can be modified to include the impact of impingement. Usually, however, impingement will operate on younger fish as well as on those recruited into the exploited stock. Yellow perch, for example, are recruited at age 3 but become vulnerable to impingement as yearlings. The simplest approach is to assume that the biomass of the impingable but unexploited portion of the stock is proportional to the exploited portion of the stock, i.e., $B_{un} = c\ B$, then as $B_I = B + B_{un}$, the equation for impingement can be written as:

$$\frac{dI}{dt} = f'\ Q\ B_I = f'\ Q(1 + c)\ B = f\ Q\ B \qquad (2)$$

where: f = impingement coefficient

f' = impingement coefficient

Q = volume flow into the plant

B = biomass of the exploited population

B_I = impingeable biomass

B_{un} = impingeable biomass not recruited into exploited stock

c = proportionality constant

The effect of changes in the biomass of the exploited stock will be examined and it will be shown that large changes

in biomass have little effect on the results.

Application of the surplus production model for assessment of entrainment requires further modification of the model. The loss of larvae and eggs by entrainment must be expressed in terms of an equivalent loss in biomass from the exploited stock. The number of eggs produced in one spawning season by the mature stock, which is usually nearly the same as the recruited stock, is

$$G_o = (B)(EUB)/2 \tag{3}$$

where G_o is the number of eggs produced and EUB is the number of eggs produced per unit of adult biomass. For yellow perch age 3 is both the age at entry into the commercial fishery and the age at maturity of females. The average number of eggs present during one spawning season is

$$\overline{G} = G_o(2 - \phi_1)/2 \tag{4}$$

where ϕ_1 is the mortality rate during the egg stage. The rate of entrainment of eggs is given by the equation

$$\frac{dG}{dt} = p' Q \overline{G} \tag{5}$$

where G is the number of eggs entrained at time t and p' is the egg entrainment coefficient. The power plant operates on the average number of eggs present. Equation (5)

can be written as

$$\frac{dG}{dt} = p' Q \frac{G_o(2 - \phi_1)}{2} = p Q G_o \qquad (6)$$

where $p = p'(2 - \phi_1)/2$ and equation (6) can be written as

$$\frac{dG}{dt} = p Q B EUB/2. \qquad (7)$$

To relate this rate of egg entrainment to change in biomass it is assumed that under equilibrium conditions each unit of biomass in the adult stock replaces itself, then

$$(EUB/2) \left(\frac{dB}{dt}\right)_e = \frac{dG}{dt} \qquad (8)$$

where $(dB/dt)e$ is the rate of biomass change as a result of entrainment. Substitution for dG/dt gives the rate of biomass change as a result of egg entrainment as

$$\left(\frac{dB}{dt}\right)_e = p Q B \qquad (9)$$

A similar approach is applied to obtain the relation between larvae entrainment and the rate of biomass decrease. The initial number of larvae produced by the G_o eggs is

$$L_o = (1 - \phi_1)G_o \qquad (10)$$

The average number of larvae is

$$\bar{L} = L_o(2 - \phi_2)/2 \tag{11}$$

where ϕ_2 is the mortality rate during the larvae stage.
The rate of entrainment of larvae is

$$\frac{dL}{dt} = h' Q L \tag{12}$$

and the rate of change in biomass resulting from larvae entrainment is

$$\left(\frac{dB}{dt}\right)_e = h Q B \tag{13}$$

where h is an entrainment coefficient for larvae.
In development of this model it is not necessary to specify the duration of the different life stages and it is not necessary to estimate ϕ_2.

Combining the above results gives the surplus production model:

$$\begin{aligned}
\frac{dY}{dt} &= q E B \\
\frac{dI}{dt} &= f Q B \\
\frac{dL}{dt} &= h Q B \\
\frac{dG}{dt} &= p Q B \\
\frac{dB}{dt} &= kB - (k/B_\infty)B^2 - qEB - fQB - pQB - hQB
\end{aligned} \tag{14}$$

Equations (14) are applied to estimate biomass of the stock and the number of eggs and larvae produced. They also are applied to examine the separate and combined impacts of impingement and entrainment on standing stock, yield, and maximum sustainable.

Estimation of Biological Parameters

The biological and fisheries related parameters of the model--k, B_{∞}, and q were estimated using commercial catch and effort data for the 3 fishery statistical districts in western Lake Erie: Ohio-1, Mich., and OE-1 in Ontario (Fig. 1). Data for 1964 to 1977 were available for these estimates from the U.S. Fish and Wildlife Service and the Ontario Ministry of Natural Resources. The major fishing gears used in these districts were 2" gill nets, shallow trap nets, and pound nets. Data for all districts were summed; pound nets were selected as the standard gear and the pound net effort necessary to make the entire catch was calculated as

$$\text{pound net effort} = \frac{\text{total catch}}{\text{pound net catch per unit effort}}$$

The results are listed in Table 1.

Table 1. Commercial catch and effort data for yellow perch in the western basin of Lake Erie (Fishery statistical districts Ohio-1, Mich, and OE-1).

year	yield*	effort**
1964	1,431,427	26,491
1965	2,208,311	20,803
1966	2,061,096	21,994
1967	2,431,039	17,187
1968	2,742,197	15,157
1969	3,428,862	15,499
1970	3,296,589	23,646
1971	2,008,141	24,903
1972	2,014,346	23,218
1973	2,246,481	30,378
1974	1,362,955	21,037
1975	1,378,398	26,547
1976	321,330	12,904
1977	807,238	20,308

*yield is in kilograms.

**effort is in lifts of pound nets.

To estimate the biological parameters a non-linear least squares method was applied to minimize the residual sum of squares

$$\sum (Y(t)_a - \hat{Y}(t)_a)^2 \qquad (15)$$

where $Y(t)_a$ is the observed annual yield for year t and $\hat{Y}(t)_a$ is the estimated annual yield for year t. Estimated yield was obtained from the solution of the yield equation. Separation of variables and integration gives annual yield as

$$\hat{Y}(t)_a = Y(t+1) - Y(t) = q\, E(t) \int_t^{t+1} B(t)\, dt \qquad (16)$$

and application of the trapezoidal rule gives

$$\hat{Y}(t)_a = q\, E(t) \left[\frac{B(t+1) + B(t)}{2} \right] . \qquad (17)$$

Biomass at time t was calculated from the solution to the biomass equation which is

$$B(t) = \left\{ \frac{k}{B_\infty (k-qE)} + \left[\frac{1}{B_o} - \frac{k}{B_\infty (k-qE)} \right] e^{-(k-qE)t} \right\}^{-1} \qquad (18)$$

where B_o is the initial biomass and is calculated as 1/q times the catch per unit of effort for the initial year.

The fit of the model is poor from 1964 to 1972 but the fit is good from 1972 to 1977 (Fig. 3). Large changes occurred in the yellow perch population between 1964 and 1977 and these changes are reflected in the catch statistics. Changes also occurred in the fishery regulations. The impingement and entrainment data were obtained during 1974 and 1975 and during this period the model describes the dynamics of the fishery well.

Eddy and Surber (1943) estimated the number of eggs produced per yellow perch female as 20,000; the eggs per unit of biomass is 65,316.

For assessment of entrainment the mortality parameter ϕ_1 for the egg stage must be determined. Values in the literature indicate that ϕ_1 is between 0.50 and 0.70 (Patterson 1979). In this study ϕ_1 was set at 0.99. This high egg mortality value results in a higher larvae entrainment impact (a larger proportion entrained), but even with this high mortality the impact of entrainment is considerably smaller than the impact of empingement. The effect on the results of different values of ϕ_1 is examined.

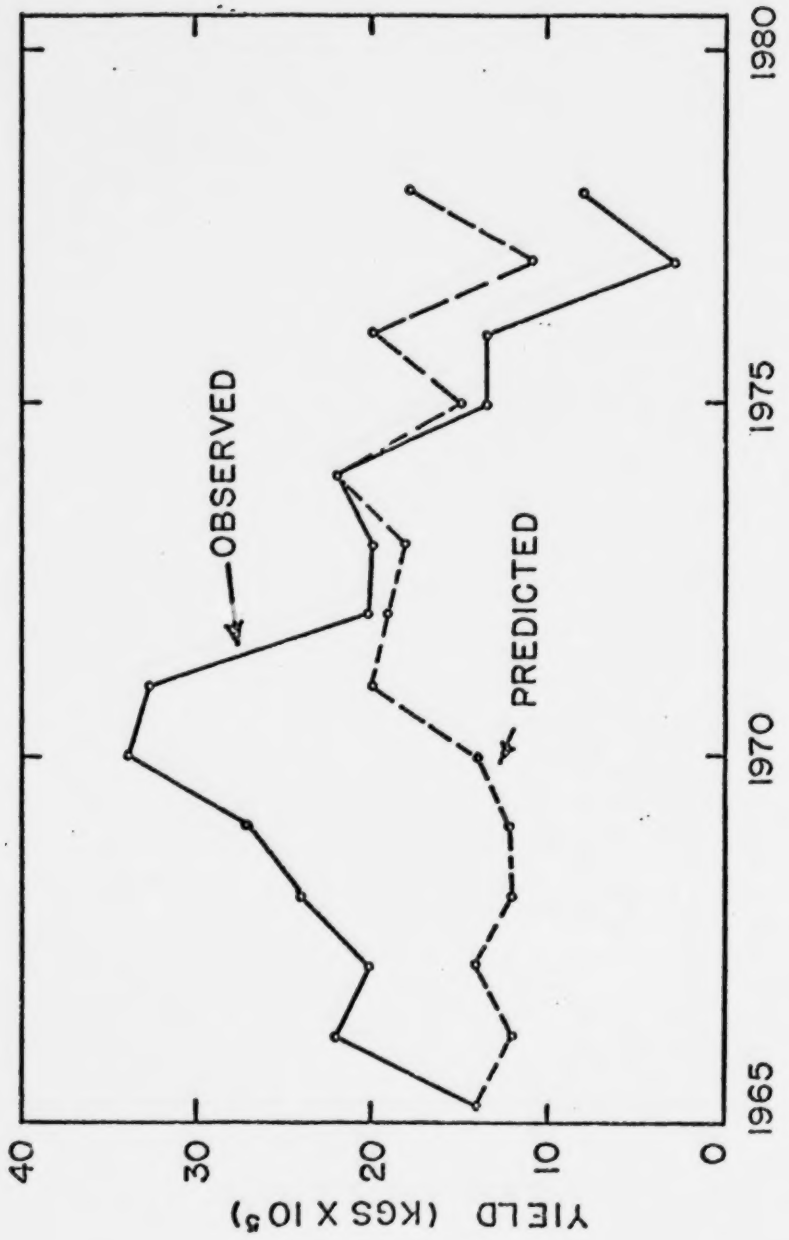

Figure 3. Observed yellow perch yield from western Lake Erie and yield calculated using the fitted surplus production model (dashed line).

Estimation of entrainment and impingement Coefficients

From estimates of annual biomass impinged, numbers entrained, and the observed volume flow the entrainment and impingement coefficients were calculated. For the dynamic pool model the estimates of numbers entrained and impinged reported by Cole (1978) and Patterson (1979) were used. Integration of the impingement equation gives

$$\Delta I = I(t+1) - I(t) = f\ Q \int_{t}^{t+1} B(t)\ dt = f\ Q\ \overline{B} \qquad (19)$$

and the impingement coefficient was estimated as

$$\hat{f} = \Delta I / Q\overline{B} \qquad (20)$$

Cole (1978) did not report egg entrainment so only impingement and larval entrainment are assessed with the surplus production model.

The larvae entrainment coefficient was estimated using the the equation

$$\hat{h} = \Delta L / Q\overline{B} \qquad (21)$$

The average biomass of the stock necessary for estimation of f and h was calculated using the surplus production model. The biomass estimates are listed in Table 2.

Table 2. Summary of power plant intake data, commercial catch, and stock size estimates.

Parameter	1972	1973	1974	1975
Yield (kgs)	2.0×10^6	2.0×10^6	2.2×10^6	1.4×10^6
Biomass (kgs)	8.7×10^6	7.4×10^6	6.5×10^6	5.2×10^6
Number impinged	1.7×10^5	2.2×10^5	1.5×10^5	1.7×10^5
Biomass impinged	4.3×10^4	5.7×10^4	4.0×10^4	4.6×10^4
Number entrained	---	2.2×10^6	8.3×10^7	2.9×10^7
Volume flow (m^3/yr)	---	---	0.186×10^{10}	---

Table 3. Summary of parameter estimates.

Parameter	Symbol	Estimate
Growth parameter	k	0.70
Catchability coefficient	q	0.00001
Carrying Capacity (kgs)	B_{∞}	12.0×10^{6}
Impingement coefficient	f	0.4891×10^{-11}
Larvae entrainment coefficient	h	0.2736×10^{-12}
Eggs per kg of female biomass	EUB	65,316

The numbers impinged, biomass impinged, and the number of larvae entrained are also listed in Table 2 . The biomass impinged was calculated using an estimated average individual weight of 0.265 kgs. Estimates of the model parameters are listed in Table 3 .

Impact of Entrainment and Impingement

The proportion of the larvae entrained and the proportion of the standing stock impinged are both small (Table 4). The impact of this entrainment and impingement on the standing stock and maximum sustainable yield is somewhat larger.

The impact of a power plant is similar to that of a fishery. For a fishery the maximum sustainable yield occurs at a biomass of $B_\infty/2$ and it is calculated as $MSY = kB_\infty/4$. For the western basin of Lake Erie the MSY of yellow perch is 2,100,000 kgs; when this yield is removed annually from the stock the stock is reduced from the carrying capacity of 12,000,000 kgs to 6,000,000 kgs. At equilibrium 35% of the stock is removed annually but this removal causes the standing stock to decrease 50% below the carrying capacity. The decrease in the size of the standing stock is larger than the proportion of the standing stock that is caught.

This same result applies to power plant entrainment and impingement. The reduction in the stock is larger than the proportion of the existing stock that is entrained or impinged.

The fitted surplus production model was applied to estimate the reduction in biomass of the standing stock and the reduction in the maximum sustainable yield caused by the Monroe Power Plant. Also, the impact of increased water withdrawl is simulated using the impingement and entrainment coefficients estimated for the Monroe Power Plant.

Under equilibrium conditions where $dB/dt = 0$, the relation between biomass of the standing stock and volume flow is

$$B = B_{\infty}\left(\frac{k - qE}{k}\right) - \left[\frac{(f + h + p)B_{\infty}}{k}\right] Q \qquad (22)$$

For every value of the parameters Q and E such that

$$k > qE + (f + p + h)Q \qquad (23)$$

the biomass of the stock will asymptotically approach an equilibrium biomass value greater than zero. The model predicts that neither fishing nor environmental impacts are likely to drive the population to extinction.

Applying the parameter estimates for the Monroe Power Plant the equations relating equilibrium biomass of the

standing stock to volume flow for impingement, larvae entrainment, and the combined impact of impingement and entrainment are:

$$B \doteq 8325771 - 8.38 \times 10^{-5} Q$$
$$B = 8325771 - 4.69 \times 10^{-6} Q \qquad (24)$$
$$B = 8325771 - 8.85 \times 10^{-5} Q$$

The equation for the combined impact is plotted in Fig. 4. Biomass of the standing stock decreases linearly as volume flow increases. The impact of impingement appears larger than the impact of entrainment but assessment of entrainment impact is less certain. The combined impacts of entrainment and impingement reduced the standing stock of yellow perch in the western basin of Lake Erie by about 2 % (Table 4).

In assessing the impact of fishing the relation between equilibrium yield and stock size is of major importance. This stock production curve, which is a parabola, gives the sustainable yield for each level of biomass. The MSY occurs at $B_\infty/2$. Under equilibrium conditions the relation between equilibrium yield and biomass for a population subjected to fishing, impingement, and entrainment is given by the equation

$$Y_e = kB - \frac{k}{B_\infty} B^2 - (f + h + p)B\,Q \qquad (25)$$

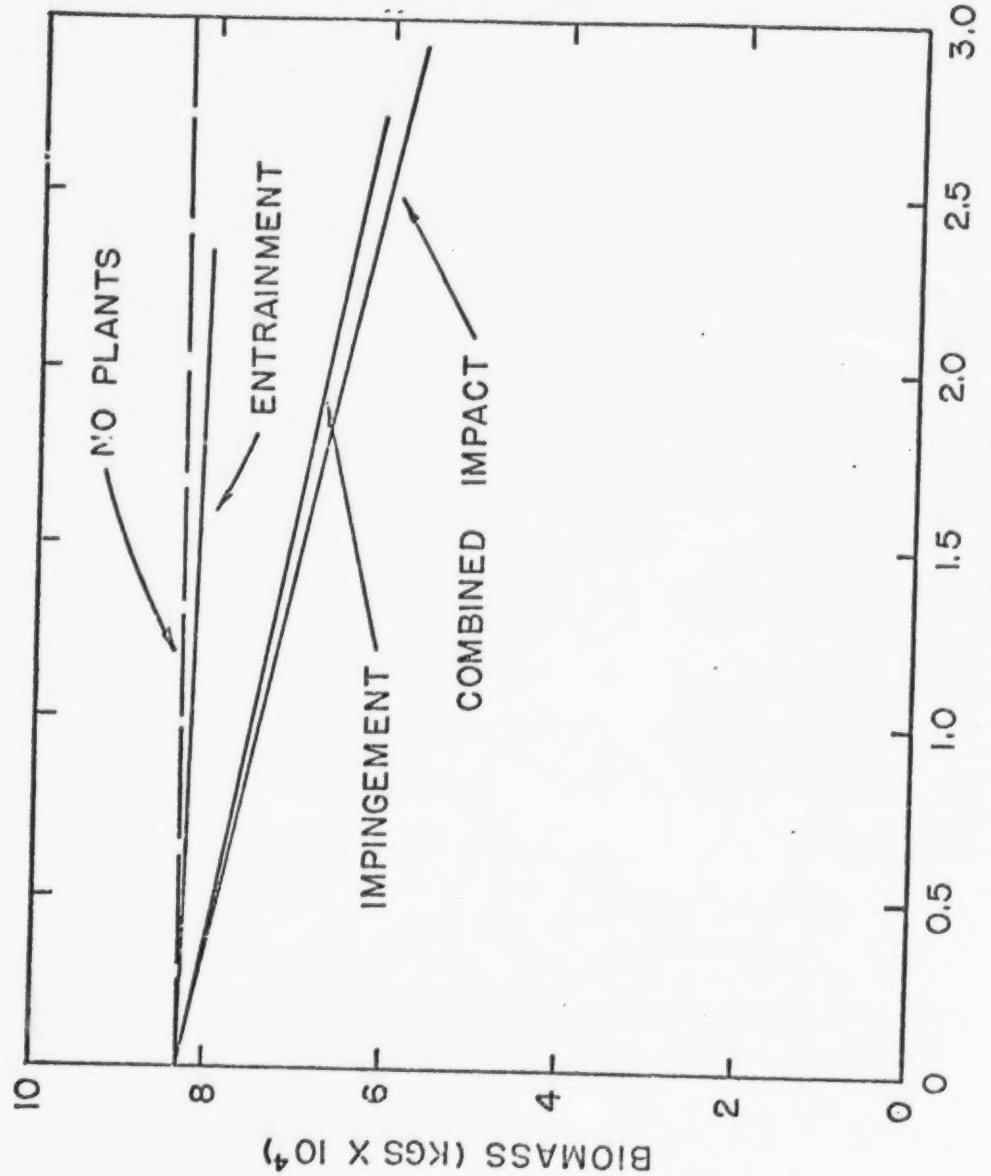

Figure 4. Equilibrium biomass of yellow perch standing stock as a function of volume of water withdrawl.

Table 4. Summary of power plant impacts.

Impact	Flow (m^3/yr)	
	0.186×10^{10}	0.29×10^{10}
Proportion of standing stock impinged	1 %	---
Proportion of larvae entrained	5 %	---
Reduction in biomass	1.98 %	3.08 %
Reduction in MSY	2.72 %	4.22 %

The relation between biomass and equilibrium yield is a parabola. Impingement and entrainment cause the entire curve to shift toward the origin (Fig. 5). Both the MSY and the biomass that would exist without fishing are reduced by impingement and entrainment. At the observed flow of 0.186×10^{10} m^3/yr the Monroe Power Plant causes only a small change in the stock production curve. An increase in water withdrawl to 2.0×10^{10} m^3/yr would cause a substantial shift in the stock production curve.

Maximum sustainable yield as a function of volume flow can be obtained from equation (25). The biomass at which the MSY occurs is

$$B' = \frac{(k - fQ - pQ - hQ)B_\infty}{2k} \qquad (26)$$

If volume flow is zero this biomass value becomes $B_\infty/2$ as is necessary. Substitution of B' into equation (25) gives the relation between MSY and volume flow as

$$MSY = \frac{kB_\infty}{4} - \frac{fB_\infty}{2} Q + \frac{B_\infty (fQ)^2}{4k} \qquad (27)$$

The relation between the MSY and volume flow is quadratic. Substitution of the parameter estimates into equation (27) gives the following equations for impacts of impingement,

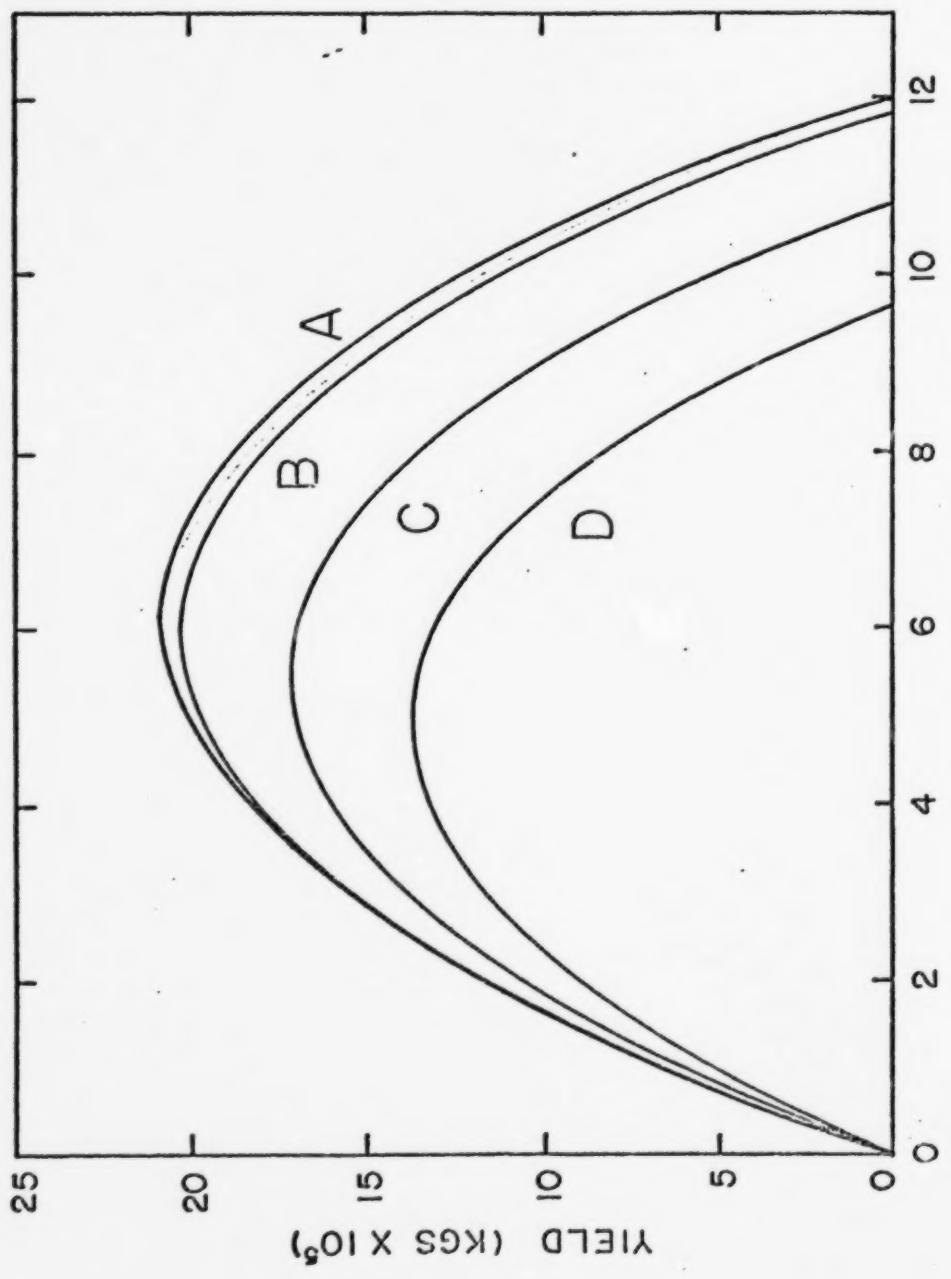

Figure 5. Equilibrium stock-production curves for yellow perch at different volume flows: A = 0, B = 0.3 X 10^{10} m^3/yr, C = 2.0 X 10^{10} m^3/yr, and D = 4.0 X 10^{10} m^3/yr.

entrainment, and the combined impacts of impingement and entrainment on the MSY of yellow perch from the western basin of Lake Erie:

$$\begin{aligned} MSY &= 2100000 - 2.93X10^{-5}\ Q + 1.02X10^{-16}\ Q^2 \\ MSY &= 2100000 - 1.64X10^{-6}\ Q + 3.21X10^{-15}\ Q^2 \\ MSY &= 2100000 - 3.09X10^{-5}\ Q + 1.14X10^{-16}\ Q^2 \end{aligned} \qquad (28)$$

The relation between the MSY and flow is essentially linear (Fig. 6); the quadratic term is small.

The surplus production model predicts that the impact of entrainment and impingement on the standing stock and MSY are considerably higher than the proportion of the standing stock entrained and impinged (Table 4). The impact on the MSY is larger than the impact on the standing stock.

Sensitivity Analysis

Predictions of the model could be in error either if the structure of the model is incorrect or if the parameter estimates are incorrect. The main reasons for the wide application of the logistic surplus production model are that it is simple and it seems to work well under a wide range of conditions. The model does fit the observed catch data well from 1972 to 1977 (Fig. 3). One main application of the model is in estimation of stock biomass. Considerable

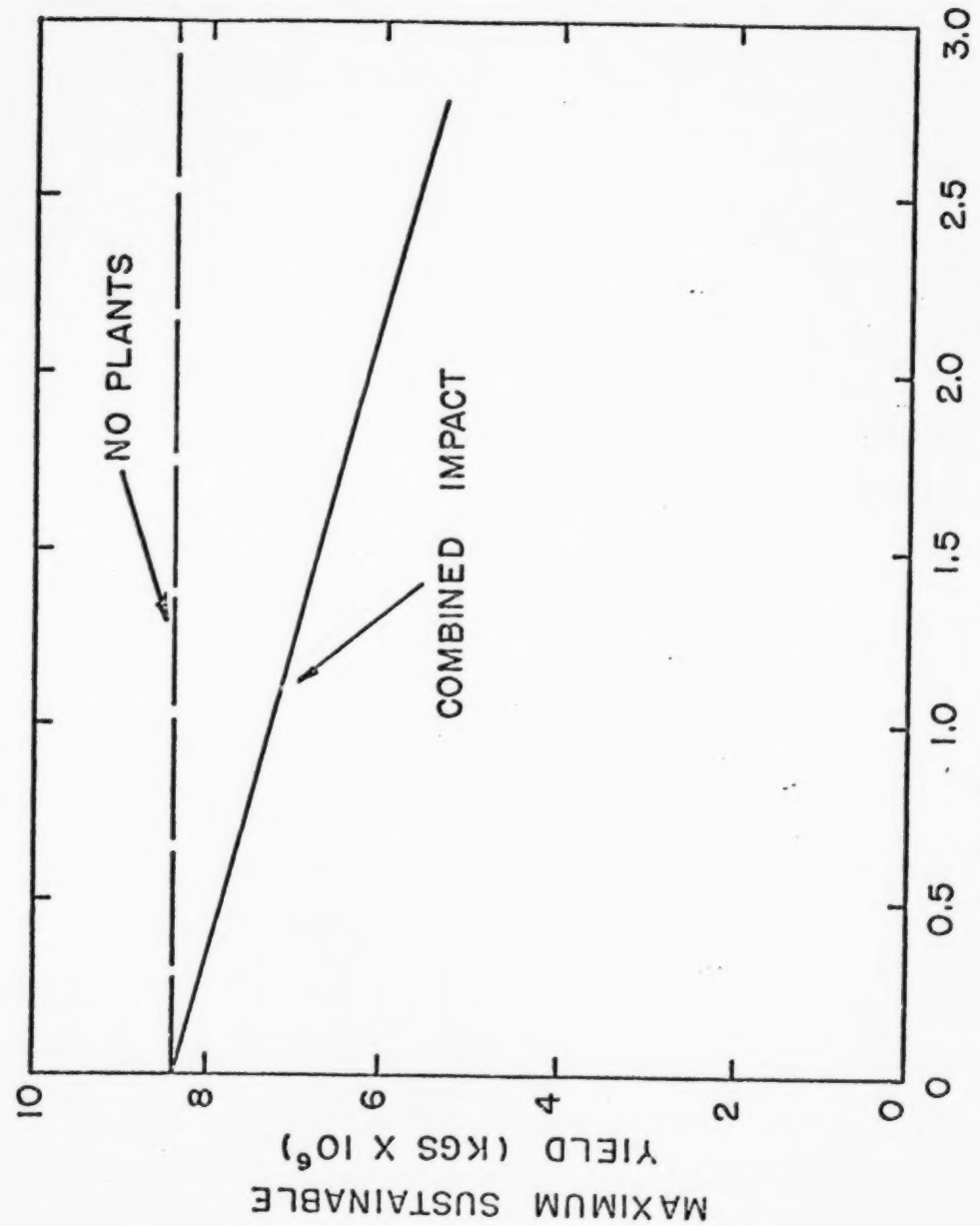

Figure 6. Maximum sustainable yield of yellow perch as a function of water withdrawl.

change in the biomass estimates does not result in large changes in the estimate of the proportion impinged (Fig. 7). The same result is true for larvae entrainment; large changes in biomass do not produce correspondingly large changes in the proportion entrained.

There are 4 parameters of the model that are of importance in evaluating the level of impact-- ϕ_1, q, k, and B_∞. The relations of biomass and the maximum sustainable yield to flow are similar so only the impact of changes in the parameters on the relation between biomass and flow will be examined. The relation between B and Q for 2 different values of q are shown in Fig. 8. The lines are parallel and the biomass entrained and impinged, which is the distance between the solid lines and the corresponding dashed lines, does not change as q changes. As q decreases, however, the estimates of population biomass decrease and the proportion impinged and entrained increases. The change in the proportions is much smaller than the change in q.

The relation between B and Q for 3 different levels of k are shown in Fig. 9. As the value of k decreases the impact increases. The lines are almost parallel and a change in k causes about the same percent change in impact. The relation between B and Q for 3 different levels of B_∞ are shown in Fig. 10). As the value of B_∞ decreases the level of impact increases. The lines converge, but

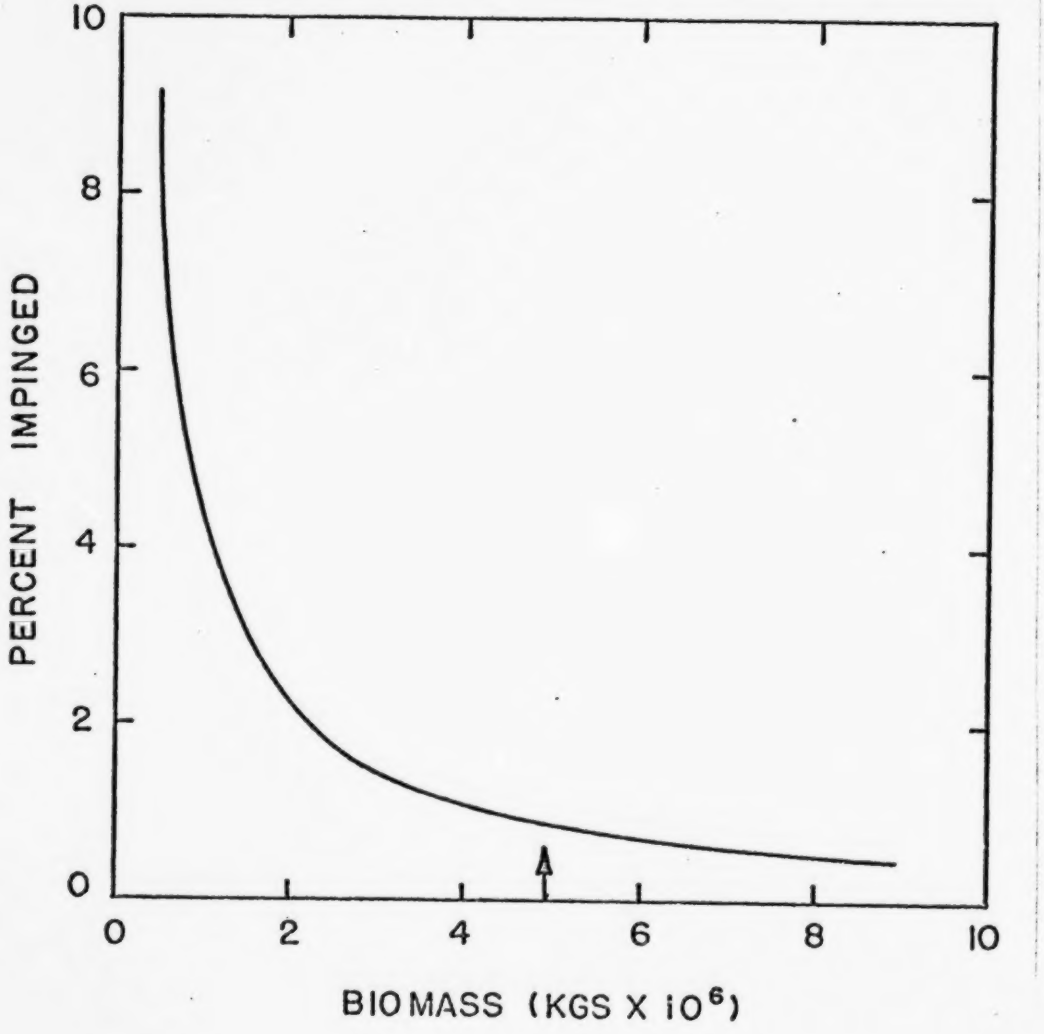

Figure 7. Relation between biomass of the standing stock and the estimate of proportion impinged. The arrow indicates the observed biomass.

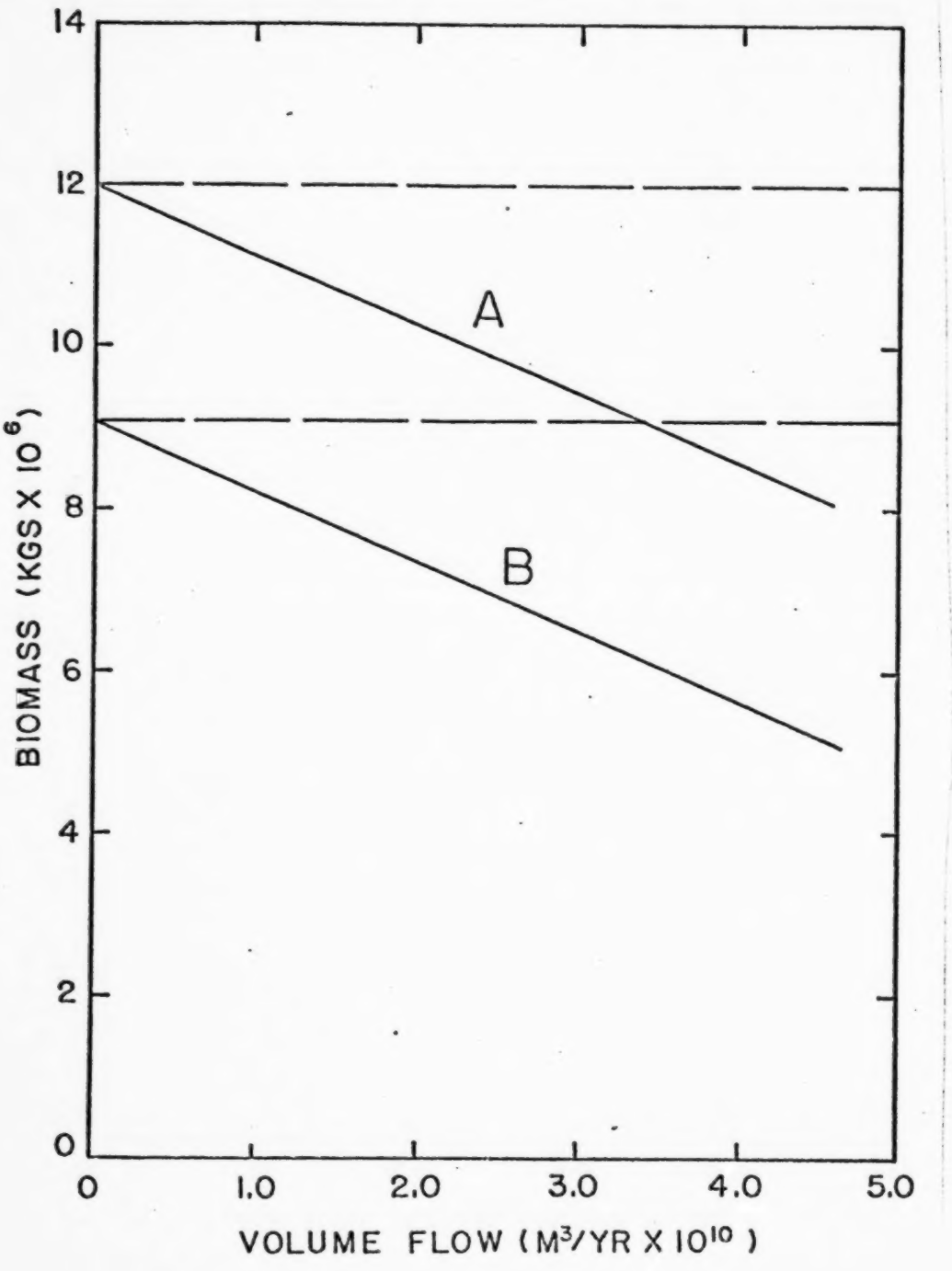

Figure 8. Relation between equilibrium biomass of the standing stock and volume flow for two values of the catchability coefficient (A = 0.000005 and B = 0.00005).

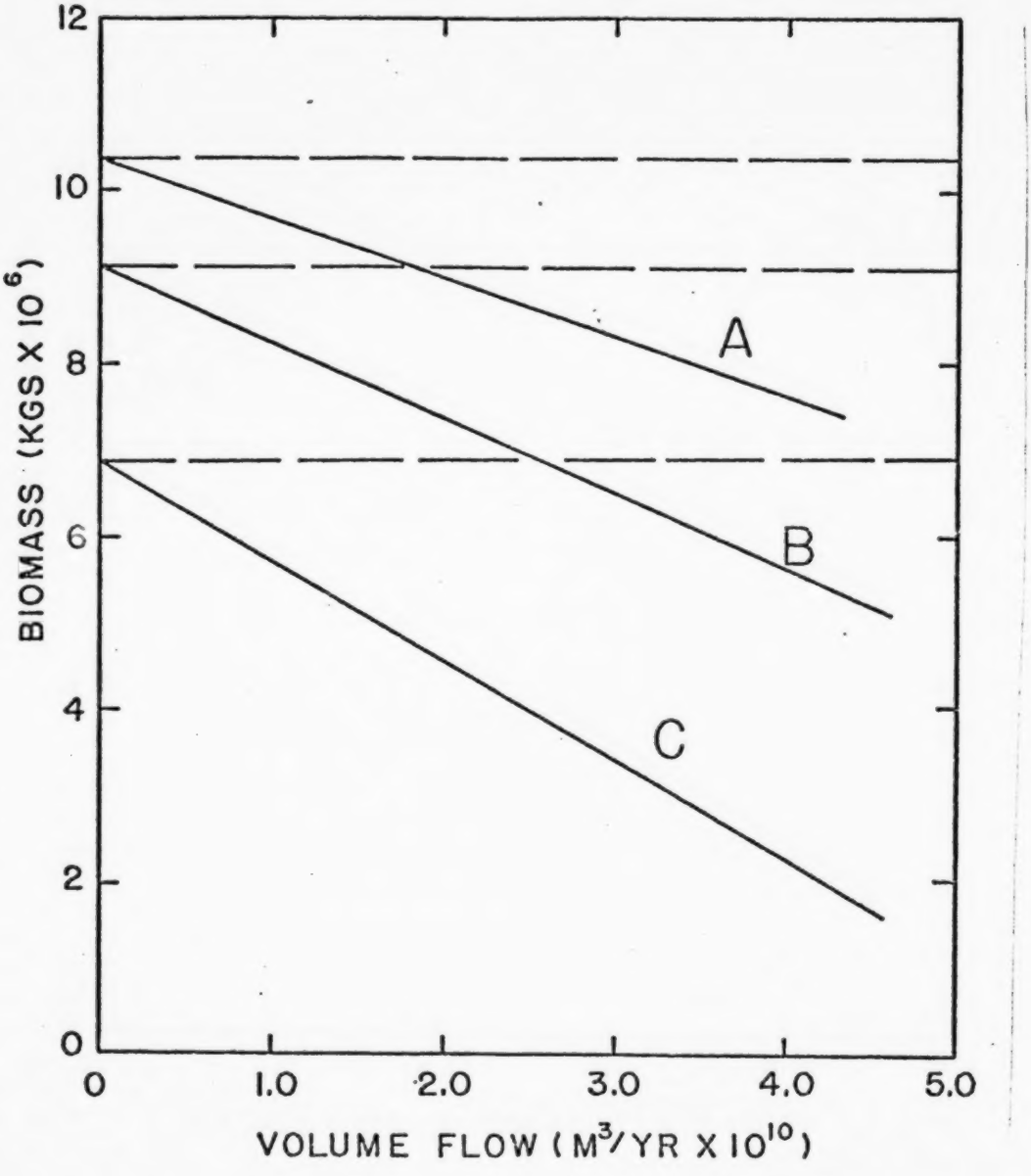

Figure 9. Relation between biomass of the standing stock and volume of water withdrawl for 3 values of the population growth parameter, k, (A = 0.70, B = 0.55, and C = 0.40).

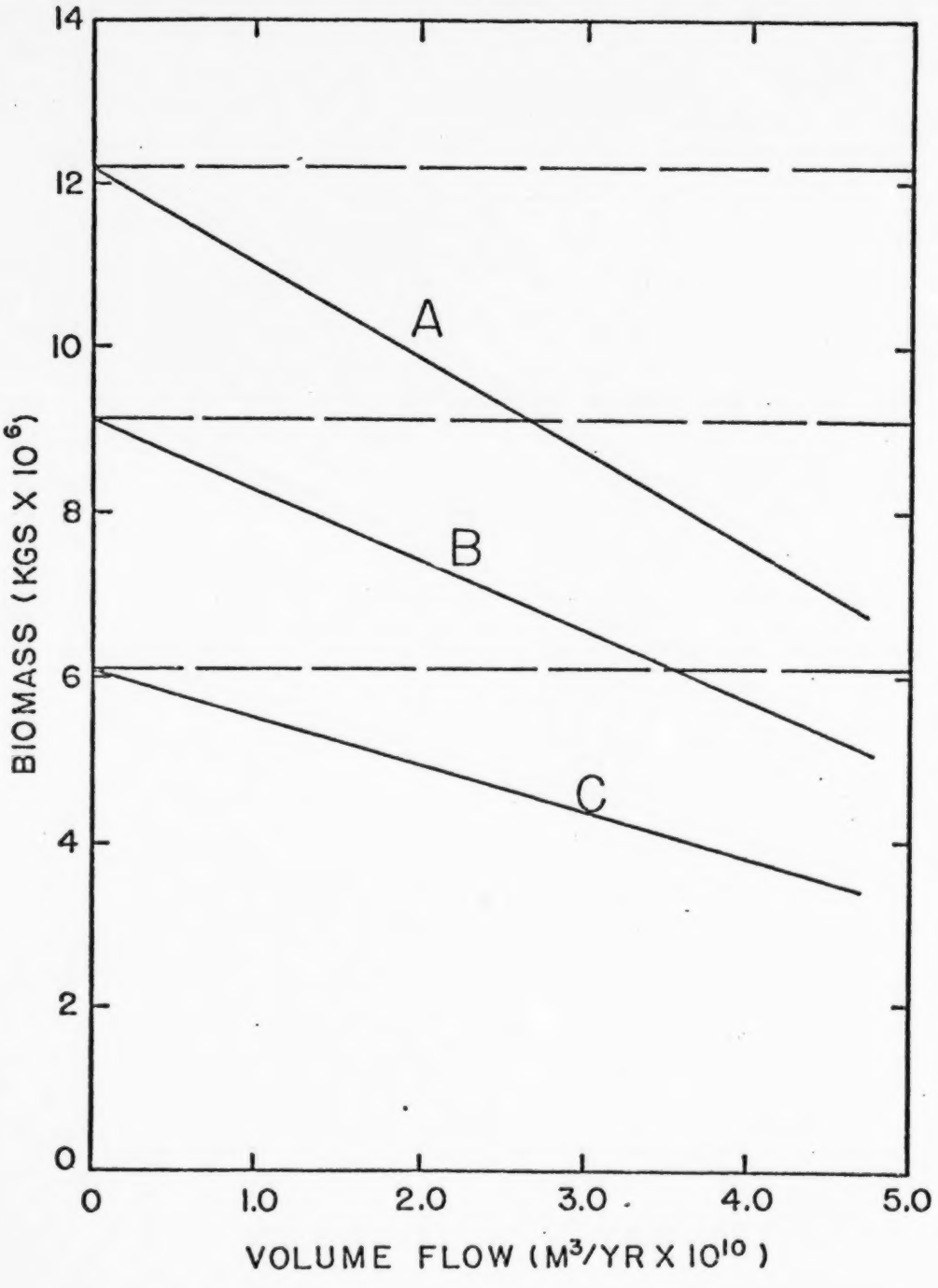

Figure 10. Relation between biomass of the standing stock and volume flow of withdrawl for 3 values of the carrying capacity, B_∞, (A = 20,000,000 kgs, B = 15,000,000 kgs, and C = 10,000,000 kgs).

the percent error in the parameter estimate is about the same as the percent error in estimation of impact.

A decrease in q, k, and B_{∞} all increase impact. In least squares fitting of the model a higher value of one or more parameters tends to be associated with a lower value of the others and it is unlikely that all parameters will be over-estimated or under-estimated. Errors in q, k, and B_{∞} tend to cancel. Because the impact is small, substantial errors of estimation of the parameters are not likely to result in an error that is of practical significance.

The egg survival parameter ϕ_1 is the most troublesome parameter as data for estimation of the parameter cannot be easily obtained. Estimates of mortality from the egg to the larvae stage vary from 0.50 to 0.75 (Patterson 1979). Within this range of values large errors in ϕ_1 produce only small changes in impact (Fig. 11). The impact begins to increase rapidly when mortality is increased to about 0.95. In this study mortality was set at 0.99 which results in a high impact of entrainment on larvae. Still, the impact of entrainment appears small compared to the impact of impingement.

In summary, the surplus production model, a conventional fishery stock assessment model was applied for assessment of entrainment and impingement impacts. Because impingement is similar to fishing considerable confidence can be placed in impingement assessments using this model. Entrainment assessment is somewhat uncertain because of the lack of

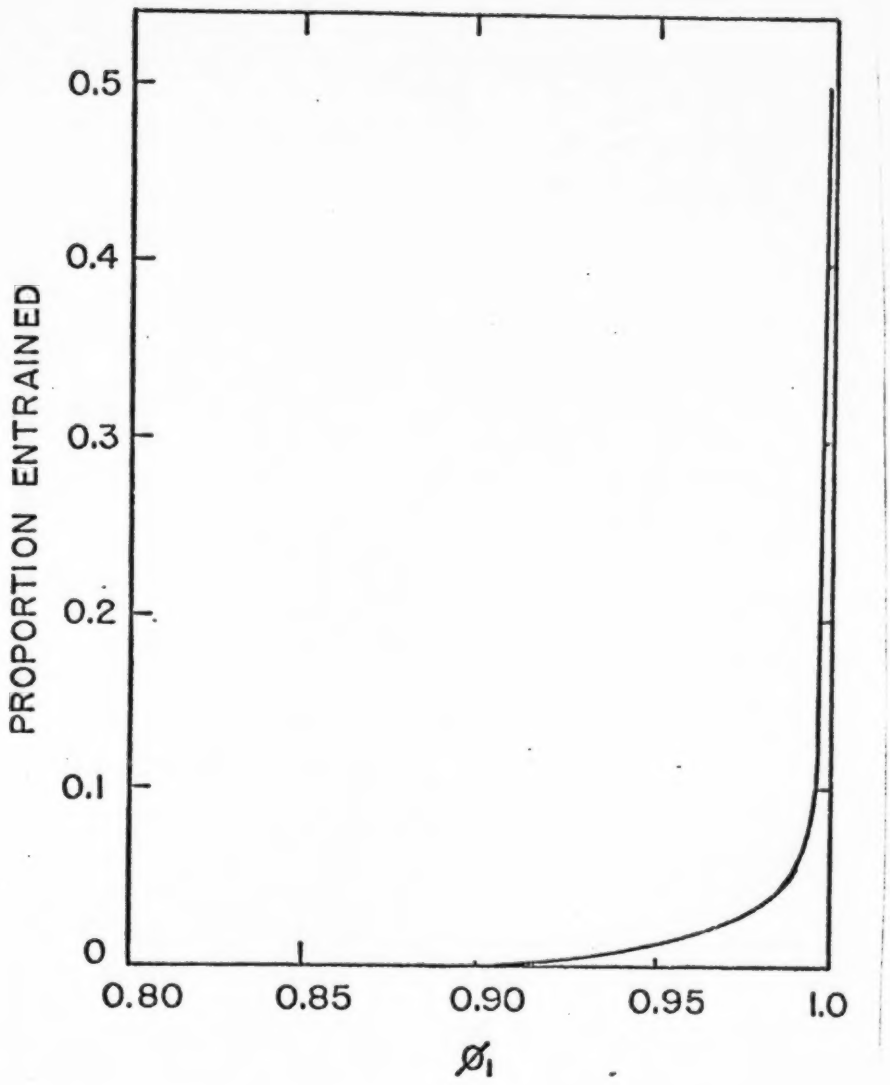

Figure 11. Relation between the proportion of larvae entrained and the egg mortality coefficient.

ecological information concerning the early life stages of fish. Most of the parameters of the surplus production model can be estimated objectively from catch and effort data and power plant entrainment and impingement data. The fitted model indicates that the level of impact is larger than is indicated by direct comparison of the numbers entrained and impinged with the standing stock, but the impact is still relatively small.

SECTION 6

DYNAMIC POOL MODEL

Model Development

The dynamic pool model is a conventional stock assessment model that has been widely applied for assessment of the impact of fishing on fish stocks (Gulland 1969, Ricker 1975). In the dynamic pool model separate equations are constructed for yield, growth, and mortality; the equations are (Gulland 1969):

$$\frac{dY}{dx} = FNW$$

$$\frac{dN}{dx} = -(F + M)N, \quad x > x_c \qquad (29)$$

$$\frac{dW}{dx} = 3 W_\infty K e^{-K(x-x_o)} \left[1 - e^{-K(x-x_o)}\right]^2$$

where:
- Y = annual yield from the fishery
- N = number of individuals of age x in the population
- W = weight of an individual of age x
- F = instantaneous fishing mortality coefficient
- M = instantaneous natural mortality coefficient
- W_∞ = asymptotic individual weight
- K = growth coefficient

x_o = theoretical age when length equals zero

x_c = age when individuals become vulnerable to the fishing gear

Two types of impact are examined in this study; each requires a different modification of the dynamic pool model. One modification assesses the impact of the Monroe Power Plant on the size and structure of the adult yellow perch population. The second modification of the model is applied to examine the impact on the biomass of the fishable part of the stock. Mortality coefficients for entrainment and impingement were incorportated into both of the modifications.

The adult population of yellow perch is all individuals one year of age and older; however, they do not enter the commercial fishery until they have reached three years of age. All adults are vulnerable to impingement. Therefore, the adult stock is separated into two subpopulations; the first is subject to natural and power plant mortalities and the second is subject to these plus fishing mortality. Separate mortality functions are developed for each subpopulation.

Impingement was modeled with the equation

$$\frac{dI}{dx} = fQN \tag{30}$$

where: I = the number of age x fish impinged

f = impingement coefficient

N = number of individuals of age x

Q = annual intake flow rate

This equation assumes that the rate of change in the number impinged is proportional to the volume flow times the number of fish of age x.

The number of individuals of age x, where x is between the age when fish become vulnerable to impingement, x_I, and the age of entry into the exploited stock, x_c, can be modelled using the following modification of the conventional mortality equation

$$N = R\, e^{-(M+fQ)(x-x_I)} \tag{31}$$

where the new terms are:

R = number of individuals of age x_I, termed recruits

x_I = age when fish become vulnerable to impingement

The number of individuals of ages greater than or equal to x_c is given by

$$N = R\, e^{-(M+fQ)(x_c-x_I) - (F+M+fQ)(x-x_c)} \qquad (32)$$

where x_c is the age at entry into the exploited stock.

Assuming constant recruitment and mortality coefficients, the size of each subpopulation can be determined by integrating the above equations with respect to age. The number of individuals between x_I and x_c years of age, denoted by N_1, is

$$N_1 = \frac{R\left[1 - e^{-(M+fQ)(x_c-x_I)}\right]}{M + fQ} \qquad (33)$$

The number of individuals x_c years of age and older, denoted by N_2, is

$$N_2 = \frac{R\, e^{-(M+fQ)(x_c-x_I)}}{M+F+fQ} \qquad (34)$$

The total size of the adult population, N, is the sum of the two subpopulations.

Entrainment operates only on eggs and larval fishes, i.e., those life stages small enough to be drawn through the intake screens. The impact of entrainment is incorporated into the model through its impact on recruitment which

is the number of eggs that survive to x_I years of age. Assuming knife edge reproduction (Ricker 1975), recruitment can be expressed in terms of larvae mortality as

$$R = L\, e^{-(m_2+hQ)\,\Delta t_L} \tag{35}$$

where the new symbols are:

m_2 = natural mortality coefficient for larvae

h = larvae entrainment coefficient

Δt_L = duration of larvae stage

L = number of larvae produced in one year

Similarly, larvae production can be expressed in terms of egg mortality as

$$L = E\, e^{-(m_1+gQ)\,\Delta t_E} \tag{36}$$

where the new symbols are:

m_1 = natural mortality coefficient for eggs

g = egg entrainment coefficient

Δt_E = duration of egg stage

E = number of eggs produced in one year

Combining the above equations, recruitment can be expressed as

$$R = E \exp\left[-(m +gQ)\Delta t_E - (m +hQ)\Delta t_L\right] \tag{37}$$

Substitution of equation (37) for R in equation (39) gives the equation for the number of individuals of age x, for x greater than x_c, as

$$N_2 = E \exp\left[-(m_1+gQ)\Delta t_E - (m_2+hQ)\Delta t_L - (M+fQ)(x_c-x_I) - (M+F+fQ)(x-x_c)\right] \quad (38)$$

Similarly, the number of individuals of age x, where x is between x_I and x_c, is given by

$$N_1 = E \exp\left[-(m_1+gQ)\Delta t_E - (m_2+hQ)\Delta t_L - (M+fQ)(x-x_I)\right] \quad (39)$$

Integrating both equation (38) and equation (39) with respect to age and taking their sum gives an estimate of the total size of the perch population being impacted at the Monroe Power Plant.

A further modification of the yield equation is necessary to assess the impact of entrainment and impingement on the fishable biomass. The biomass of a cohort at age x, B, is given by B = NW. Substitution for N and W and integration gives:

$$B = W_{\infty} E \exp\left[-(m_1+gQ)\Delta t_E - (m_2+hQ)\Delta t_L + (M+fQ)(x_c-x_I)\right] \cdot \sum_{i=0}^{3} \frac{U_i\, e^{-iK(x_c-x_o)}}{F+M+iK+fQ} \qquad (40)$$

where $U_o = 1$, $U_1 = -3$, $U_2 = 3$, and $U_3 = -1$.

Equations (38), (39), and (40) are applied to a cohort of eggs to determine the impact of both entrainment and impingement on the structure and size of the impingable stock and the fishable biomass. Under steady-state conditions the biomass of a cohort integrated over its lifetime equals the biomass at any point in time and the survival curve of a cohort during its lifetime is the same as the population survival curve at any point in time (Beverton and Holt 1957).

Estimation of Parameters

The growth parameters for yellow perch, K, W_∞, and x_o, were estimated using the conventional methods described by Gulland (1969) and the data reported by Jobes (1952) on a sample of 23,158 fish collected from Lake Erie. Parameter estimates are listed in Table 5. Other more recent data sets for yellow perch in the Great Lakes and elsewhere indicate only a small range of parameter values (Brazo et al 1975, Thorpe 1977).

For the dynamic pool model the power plant related parameters were estimated using entrainment and impingement estimates reported by Anon (1976). Data for assessment of the impact of the Monroe Power Plant are based on 52 weeks of sampling at the site, from April 1975 to April 1976, with entrainment and impingement studies being conducted concurrently (Anon 1976). The mean operational load during the sampling days was 55.7% of the maximum rated capacity.

Over the 12-month period an estimated total of 861,000 fish were impinged, of which 51.8% were gizzard shad and 14.2% (122,301) were yellow perch.

An estimated 21,392,679 larvae were entrained during the study period, of which nearly 45% were gizzard shad. Yellow perch accounted for approximately 23% of the total.

Table 5. Summary of estimates of parameters that were held constant over all cases.

Parameter	symbol	value
Growth coefficient	K	0.45
Asymptotic weight (kgs)	W_∞	0.34
Theoretical age when length is zero (yrs)	x_o	0.21
Number of eggs produced per female	E_f	20,000
Duration of egg stage (yrs)	Δt_E	0.027
Minimum proportion of eggs hatching	μ	0.25
Duration of larvae stage (yrs)	Δt_L	0.57
Impingeable age	x_I	1
Age at entry to fishery	x_c	3

From April 1975 to April 1976 a total of 13,083,131 eggs were entrained at Monroe. Only 0.7% of the eggs were yellow perch, but 77% of the eggs were not identified.

Entrainment coefficients for larvae and eggs were calculated under 4 different sets of conditions that are discussed later. For each case the following equations were applied. The egg entrainment coefficient was estimated as

$$\hat{g} = \frac{\Delta E}{QE} \qquad (41)$$

where E is the number of eggs produced and ΔE is the number of eggs entrained. Of the eggs identified 86,528 were yellow perch, but 77% of the eggs were not identified. Assuming the same species and proportions for eggs not identified as for those that were identified gives a total of 379,411 yellow perch eggs entrained. The entrainment coefficients were calculated using both of these values for egg entrainment

(Table 6). Volume flow was estimated as 1.6×10^9 m^3/yr.

The number of eggs produced is given by the equation

$$E = E_f \, p \, N_2 \tag{42}$$

where: E_f = the average number of eggs produced per female

p = the proportion of sexually mature adult females in the population

N_2 = the total number of sexually mature adults which for yellow perch is also the exploited population

The proportion of females is about 0.50 (Jobes 1952).

For estimation of N_2, the number of mature adults, equation (34) is applied. An equation for estimation of R in equation (34) was obtained from the catch equation

$$\frac{dC}{dx} = F \, N. \tag{43}$$

Substition of N from equation (34) into the catch equation; integration, and solution for R gives

$$R = (M + F + fQ) \, C \, e^{-(M+fQ)(x_c - x_I)} \tag{44}$$

Table 6. Estimates of parameters and variables that were varied from case to case.

Variable or Parameter	Symbol	Case I	Case II	Case III	Case IV
Fishing mortality coefficient	F	0.22	0.51	0.51	0.22
Natural mortality coefficient	M	0.22	0.60	0.22	0.60
Size of mature population	N	$3.43X10^{7}$	$1.48X10^{7}$	$1.48X10^{7}$	$3.43X10^{7}$
Eggs produced	E	$3.43X10^{11}$	$1.48X10^{11}$	$1.48X10^{11}$	$3.43X10^{11}$
Larvae produced	L	$8.57X10^{10}$	$3.70X10^{10}$	$3.70X10^{10}$	$8.57X10^{10}$
Total population size (numbers)	N	$7.22X10^{7}$	$7.82X10^{10}$	$4.18X10^{7}$	$1.41X10^{8}$
Impingement coefficient	f	$1.06X10^{-12}$	$9.77X10^{-13}$	$1.83X10^{-12}$	$5.42X10^{-13}$
Egg entrainment coefficient	g^{a}	$1.57X10^{-16}$	$3.65X10^{-16}$	$3.65X10^{-16}$	$1.57X10^{-16}$
Egg entrainment coefficient	g^{b}	$6.91X10^{-16}$	$1.60X10^{-15}$	$1.60X10^{-15}$	$6.91X10^{-16}$
Larval entrainment coefficient	h	$3.64X10^{-14}$	$8.44X10^{-14}$	$8.44X10^{-14}$	$3.64X10^{-14}$

[a]Assumes 86528 eggs entrained which is the observed number.

[b]Assumes 379,411 eggs entrained which accounts for the 77% unidentified eggs.

where C is the annual catch in 1975 which was estimated from commercial catch and average weight data as 7.5×10^6.

The mortality rates M and F are difficult to estimate because adequate data for separation of natural and fishing mortality are not available. In this study results were examined using a range of mortality coefficients. Survival data for the period 1971-1975 (Scholl 1976) give the total mortality coefficient, Z, as 0.82. The range for the fishing mortality coefficient is based on the assumption that 20 to 40 percent of all perch vulnerable to fishing will be harvested annually by sport and commercial fishermen. Under this assumption, the instantaneous fishing mortality coefficient, F, is in the interval (0.22, 0.51). A reasonable range of values for M is (0.22, 0.60) which gives values of Z in the interval (0.44, 1.11) which includes the estimated value of 0.82 near the mid-point. Hartman (1977) estimated the instantaneous natural mortality coefficient, M, to be in the range of 0.22 to 0.29.

To estimate R the value of f needs to be estimated. Estimation of R with a range of reasonable values of f indicated that f had only a negligable effect on R so for simplicity f was assumed zero for estimation of R. If the effect of f is large, the value of f can be estimated iteratively using equations (44) and (47).

The larvae entrainment coefficient was estimated as

$$\hat{h} = \frac{\Delta L}{QL} \qquad (45)$$

where ΔL is the number of larvae entrained annually which was estimated as 4,996,924 in 1975. The annual production of larvae was estimated as

$$\hat{L} = \mu E_f p N_2 \qquad (46)$$

where μ is the proportion of eggs that hatch into larvae. Scholl (1976) reported that the minimum hatching success for yellow perch, μ, is approximately 25%.

Yellow perch may spawn as early as late April or early May (Scholl 1976). Hatching takes place in 8 to 10 days but may take longer (Scott and Crossman 1973). Assuming knife edge reproduction and that the average time required for hatching is 10 days the duration of the egg stage, Δt_E, is 0.0274.

Larvae perch are recruited into the young-of-the-year stage 25 days after hatching (Patterson 1976). Combining the 25 day larvae stage with the following six-month period as young-of-the-year gives a yearly fraction when the fish are vulnerable to entrainment, Δt_L, of 0.5687.

At one year of age the adult perch become vulnerable to impingement so $x_I = 1$. At three years of age they are recruited into the exploited stock ($x_c = 3$) and sexual maturity also is attained by the age of 3 for the majority of females (El-Zarka 1957).

The impingement coefficient was estimated as

$$\hat{f} = \frac{\Delta N}{QN} \tag{47}$$

where the number impinged, N, was estimated as 122,301. All estimates are listed in Table 5 and Table 6.

Results and Discussion

The impact which an additional mortality source, such as a power plant, will exert upon the fishable biomass and the population size is a function of natural and fishing mortality. Four cases are examined that represent different possible combinations of natural and fishing mortality rates. This provides the assessment of a wide range of impacts on the yellow perch population size and biomass. In all cases entrainment impact is similar with egg entrainment coefficients based on 86,528 eggs and 371,411 eggs entrained; those impacts listed in Table 7 were calculated with the observed number of eggs entrained.

Case I assumes that the adult population is experiencing low levels of fishing and natural mortality. This results in a fairly even balance of unexploitable and exploitable fish; with a total population estimated at about 72 million individuals. Under these conditions the proportion of adults impinged is 1.70×10^{-3} (Table 7).

Total egg production for the population is approximately 3.43×10^{11} and the proportion entrained is about 2.52×10^{-7}. The total number of larvae produced is 8.57×10^{10} and the proportion entrained is 5.83×10^{-5}. Under Case I the Monroe Power Plant operating at maximum capacity reduces the total adult population by 508,934 fish or 0.71 percent. At full operating capacity the biomass is reduced from 7,593,783 kgs to 7,493,341 kgs; a decrease of 100,442 kgs, representing 1.32 percent of the fishable biomass.

Case II assumes that the yellow perch population is subject to high fishing and high natural mortality. These conditions produce a population dominated by young fish between the ages of one and three. The total population is estimated at about 78 million; which is similar to that for the Case I population and hence the proportion impinged is also similar; 1.56×10^{-3} (Table 7). The number of sexually mature females is much less in this case and egg and larval production also are less, resulting in a greater entrainment impact. Under Case II criteria, the proportions

of eggs and larvae entrained is 5.85×10^{-7} and 1.35×10^{-4}, respectively. In spite of the greater impact due to entrainment, it was found that the total impact decreased the adult population by only 253,460 or 0.32 percent. The fishable biomass was reduced from 2,592,904 kgs to 2,572,269 kgs; a reduction of 20,635 kgs or approximately 0.80 percent. This represents a substantially lesser impact than that which results under Case I criteria.

Case III assumes the population is subject to low natural and high fishing mortality rates. These conditions produce a relatively small population of approximately 42 million fish which, again, is dominated by immature adults. The number of mature adults is the same as in Case II and therefore the egg and larval production also will be the same. Identical results also are obtained for egg and larval entrainment; i.e., the proportion of eggs and larvae entrained being 5.85×10^{-7} and 1.35×10^{-4}, respectively. The proportion impinged, however, is greater because of the smaller population size and is approximately 2.92×10^{-3}.

The impact of the Monroe Power Plant operating at maximum capacity reduces the population by 362,412 fish, which is equivalent to a percentage reduction of 0.87. The fishable biomass is reduced from 2,875,899 kgs to 2,825,532 kgs, which is a decrease of 1.75 percent.

Case IV assumes a high natural mortality and a low fishing mortality operating on the population. These conditions produce a large population of approximately 143 million fish; 109 million of which are between the ages of one and three. The number of sexually mature females is quite small relative to the size of the population and is, in fact, the same as for Case I. The number of eggs produced is 3.43×10^{11} and the number of larvae produced is 8.57×10^{10}. It follows that the proportion of eggs and larvae entrained also is the same; 2.52×10^{-7} and 5.83×10^{-5}, respectively. Due to the large population size the proportion impinged is only 8.56×10^{-4}. Under the condition of a maximum flow rate the population size is reduced by 286,132 or 0.2 percent. The fishable biomass is decreased from 6,472,418 kgs to 6,440,565 kgs or 0.50 percent of the total.

These results indicate that the Monroe Power Plant has a relatively small impact on the yellow perch population in the Western basin of Lake Erie. The maximum reduction in fishable biomass of 1.75% occurs with a low natural mortality and a high fishing mortality, and these conditions might be most representative of the actual conditions in the lake. This impact is not large, but there are several other power plants located on the Western basin of Lake Erie and many municipal and industrial water intakes.

Table 7. Summary of power plant impacts on eggs, larvae, size of standing stock, and biomass of fishable stock assuming full flow.

Impact	Case			
	I	II	III	IV
Eggs (86,528 entrained)				
proportion entrained	$2.52X10^{-7}$	$5.85X10^{-7}$	$5.85X10^{-7}$	$2.52X10^{-7}$
Larvae ($4.99X10^{6}$ entrained)				
proportion entrained	$5.83X10^{-5}$	$1.35X10^{-4}$	$1.35X10^{-4}$	$5.83X10^{-5}$
Impingeable population (122,301 impinged)				
proportion impinged	$1.69X10^{-3}$	$1.56X10^{-3}$	$2.91X10^{-3}$	$8.56X10^{-4}$
Population reduction*				
number	508,934	253,460	362,412	286,132
proportion	$7.05X10^{-3}$	$3.24X10^{-3}$	$8.65X10^{-3}$	$2.00X10^{-3}$
Biomass reduction*				
kilograms	100,442	20,635	50,367	31,853
proportion	$1.32X10^{-2}$	$7.96X10^{-3}$	$1.75X10^{-2}$	$5.00X10^{-3}$

*Reduction resulting from impact of entrainment and impingement of power plant operating at full capacity of 2.9×10^{9} m^3/yr.

SECTION 7

COMPARISON OF METHODS

The two models are structurally entirely different and the data applied for parameter estimation are entirely different. The surplus production model combines all ages together and population parameters are estimated from catch and effort data. The dynamic pool model follows a cohort throughout its lifetime and parameters are estimated from age specific growth and mortality data. Total catch for 1975 is applied to estimate recruitment in the dynamic pool model and this is the only connection between the two models. The two approaches are entirely independent.

The two models give similar estimates of impact. The surplus production model gives the reduction in biomass at full pumping capacity as 3.08% and the dynamic pool estimate is about 1% to 3.5%. The larvae entrainment estimates of the two models are considerably different. Setting the egg mortality coefficient at 0.99 in the surplus production model results in a smaller number of larvae and a larger proportion entrained. The estimate obtained with the dynamic pool model is based on actual estimates of the population parameters and should be more accurate. Even with a high rate of entrainment mortality the impact on the

exploited stock is not large.

The results of the two models are similar and the main criterion in selecting between them is the ease of application. All of the surplus production model parameters except eggs per unit biomass and mortality of eggs and larvae can be estimated objectively from catch and effort data. If a large amount of such data are available the surplus production model is easily applied. The dynamic pool model requires age specific growth and mortality data and separation of natural and fishing mortality. The surplus production model can be applied for estimation of the fishing mortality coefficient. Application of the two models together gives nearly independent estimates of impact and enables assessment of impacts with some confidence.

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